Emerging Issues: Changing Paradigms, Unseen Trends, Neglected Science

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"It is the theory which decides what we can observe" ~ Albert Einstein

Introduction

What ecological fate awaits Puget Sound? What is the likely state of the Puget Sound ecosystem if we continue our present management practices? The historical widespread belief that Puget Sound offers endless natural bounty for the taking, clean waters, and will never become like the Chesapeake or the Hudson River still lingers. We have assumed that natural circulation is sufficient to "flush it all away." But the recent listing of several salmon species under the Endangered Species Act has served as a wake-up call that all might not be well in our beloved Puget Sound. The struggle to maintain harvestable shellfish is a reminder that all we do ends up in the aquatic environment.

With population numbers in the Puget Sound Basin over five million and predicted to double in the next 40 years, cumulative effects have become a reality. To better grasp the implication of these numbers—if today everyone living in the Puget Sound watershed were to visit the 2,300 miles of beaches, they would stand 2-feet apart—almost shoulder to shoulder. In 40 years, we'll have to stand sideways to fit. Only recently public efforts have begun, recognizing that impacts on a *per capita* basis must be reduced to even maintain our current level of ecosystem functions (Washington Department of Ecology 2001a) (Ecology 2001b).

I offer that we have been lulled into a false sense of complacency, that the marine and estuarine ecosystem is not as healthy as assumed, and that if one were to look at other estuaries in advanced stages of degradation, one would find there were disturbingly similar early signs of ecosystem stress in them as we are now seeing in Puget Sound. There is a suite of indicators of stress, often first found locally in poorly circulating embayments, that we should be looking for and monitoring carefully. We must be correcting the underlying causes of these symptoms, which are well known, least we fall prey to our provincial Pollyanna paradigm, and the symptoms spread Soundwide—as they have elsewhere.

We have not been looking for trouble because we don't think there is any.

Currently Unconnected Signs of Ecosystem Stress of Puget Sound

What signs are there? Table 1 lists various declines of biological resources, changes in physical water quality parameters, and anecdotal evidence of changes. While these have not been formally viewed as connected in any way, one should assume they are connected and in fact present a clear pattern as seen in other estuaries.

Table 1. Indicators of ecosystem stress.

Indicator	Species or Area
Decline in fish populations	Salmon, rockfish, groundfish, forage fish (some herring populations) (West 1997)
Decline in bird populations	Western grebes, surf scoters (Puget Sound Water Quality Action Team 2000)
Increase in areas exhibiting hypoxia	Hood Canal, South Puget Sound embayments, under algal mats (Newton and Reynolds Draft.)
Increase in "green tides"	Ulvoid blooms forming mats (Frankenstein 2000)
More persistent and widespread harmful algal blooms	Shellfish closures due to paralytic shellfish poisoning, domoic acid (Determan 1999)
Loss of eelgrass beds	Largely anecdotal, in semi-enclosed bays such as Quartermaster Harbor, Sinclair Inlet
Loss of the Protection Island *Nereocystis* bed	See Berry (this proceedings)
Discovery Bay "anomaly"	Anecdotal, loss of shellfish, salmon, seaweeds; no apparent reason

Lessons Learned From Other Estuaries

Massachusetts Embayments
In many enclosed or semi-enclosed embayments on the Massachusetts coast, eelgrass beds have been declining as a result of overgrowth by filamentous red seaweeds such as *Gracilaria*. Studies in Waquoit Bay on Cape Cod have shown this is the result of eutrophication, and the source of nutrients is groundwater. (See www.capecod.net/waquoit/bib.htm for a complete list of references). "Properly functioning" septic systems introduce large amounts of nitrogen into the groundwater plume in highly porous glacial soils. Nutrients enter the embayments, and the seaweeds are more efficient in nutrient uptake and respond more quickly. This cause/effect has been modeled and quantified (Valiela and others 1997). Septic systems are being installed which de-nitritrify effluent.

Chesapeake Bay
The Chesapeake Bay ecosystem has suffered dramatic loss of valuable fisheries. Harmful algal blooms have resulted in the decertification of shellfish beds, and crab and oyster fisheries have declined. This loss has been linked to eutrophication, which caused phytoplankton blooms, then loss of water clarity and light penetration. The resultant loss of benthic submerged aquatic vegetation (SAV), which provided critical habitat for most of the fisheries species, was deemed catastrophic. SAV was chosen as the indicator of ecosystem health and monitoring the extent of SAV beds has been the major tool for determining the effectiveness of restoration. (The Chesapeake Bay Program 2001)

Baltic Sea
The Baltic Sea is a largely enclosed brackish ecosystem whose watershed includes parts of Europe, Eastern Europe, Russia, and Scandinavia. (Gren and others 2000) Degradation and loss of fisheries started in the Middle Ages. During the 20th century, widespread areas of the benthos have become hypoxic, harmful plankton blooms occur continuously, and fisheries have collapsed. Aerial deposition is recognized as a major source of nutrients and contaminants. Major efforts to clean up the area are complicated by the mutli-national nature of the watershed.

How is Puget Sound Doing? Where are We Headed?

If one examines the list (Table 1) of "unconnected signs" with those identified in other estuaries, it is obvious that there are disturbing similarities. In other estuaries, the collapse of fisheries is connected to loss of habitat and that loss of habitat is the result of large-scale degradation in water quality.

A recent study (Bricker and others 1999) has identified eutrophication as the primary or underlying stressor in many semi-enclosed coastal ecosystems. Primary expressions of the increased nutrient input are increased chlorophyll a levels and increased biomass of epiphytes and macroalgae (seaweeds). Secondary symptoms include loss of submerged aquatic vegetation, harmful algal blooms, and low dissolved oxygen. Table 2 ranks these expressions for various places in Puget Sound and the coastal estuaries. All areas (other than the Columbia River estuary) are considered to have a moderate or high level of eutrophication.

Table 2 Eutrophic conditions, symptoms, and influencing factors (Modified from: Bricker and others 1999)

		Symptom Expression						**Influencing Factors**		
		Primary			**Secondary**					
Estuary	**Eutrophic**	Chlorophyll a	Epiphytes	Macroalgae	Low Dissolved Oxygen	SAV Loss	Nuisance/ Toxic Blooms	Overall Human influence	Susceptibility	Nitrogen Input
Columbia River	Low	High	No Expression	No Expression	No Expression	No Expression	Moderate	Low	Low	Low
Willapa Bay	Moderate	Moderate	No Expression	High	No Expression	Moderate	Moderate	Low	Low	Moderate
Grays Harbor	Moderate	Moderate	No Expression	High	No Expression	?	Moderate	Low	Low	Moderate
Puget Sound	Moderate	High	No Expression	High	Moderate	Moderate	Moderate	Low	Low	Moderate
Hood Canal	High	High	?	?	Moderate	?	No Expression	High	High	Low
Whidbey Basin/ Skagit Bay	Moderate	High	?	?	Low	?	Low	Moderate	Moderate	Moderate
South Puget Sound	High	High	?	No Expression	Low	?	No Expression	High	High	Moderate
Port Orchard System	Moderate	High	?	High	Low	Low	Moderate	Moderate	Moderate	Moderate
Bellingham/ Padilla/ Samish Bays	Moderate	High	?	Moderate	No Expression	No Expression	Moderate	Moderate	Moderate	?
Sequim/ Discovery Bays	Moderate	High	?	High	Low	?	Moderate	Moderate	Moderate	?

Key:

No Expression	(white)
Low	(light grey)
Moderate	(grey)
High	(dark grey)
Insufficient Data	?

If one were to track ecosystem health over time, the theoretical curve might look something like Figure 1. Ecosystem health degrades over time fundamentally because an increasing population exploits more and more resources and inputs more and more pollutants. At some point in time, efforts are made to restore the health and the assumption is that the curve will trend upward over time.

I would offer that Puget Sound is still somewhat high on the curve and has some distance to go downward before effective restoration is likely to take place. Whether Puget Sound takes trajectory A ("keep our heads in the sand and hope it all goes away") or trajectory B (An ounce of prevention….) remains to be seen.

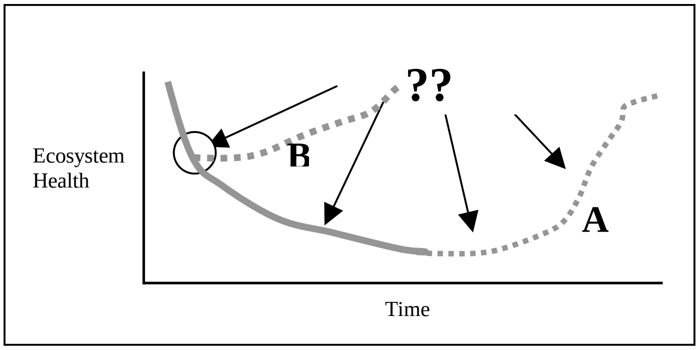

Figure 1. Environmental Health and Puget Sound

Data or issues not currently well-examined, missed or misinterpreted

If one takes the list of stressed ecosystem signs, combines them with the list of data or issues from other areas, and then thinks about what is not being done in the Puget Sound area, and should be done, I would offer the following as a good monitoring and research agenda.

Inputs

Atmospheric Deposition

In Baltic Sea, atmospheric deposition is a major source of toxics and nutrients (nitrogen) into the aquatic system, not only from direct deposition on the sea surface, but also from terrestrial surfaces then washed into the aquatic system (Gren and others 2000). Input into Puget Sound has been largely ignored or unquantified. Also, toxics are concentrated in the microlayer (see below).

Groundwater (nonpoint sources)

Up to 18% of the freshwater input into Puget Sound is from groundwater (Staubitz and others1997) The inputs are hard to measure—they are intertidal seeps, springs, small streams, some being underwater. There have been few measurements of water quality in this input. Thom (others 1988) showed significant nutrient inputs from a small urban watershed.

New chemicals with sub lethal effects

Discussed by Collier in this session.

Appropriate Scales—based on exposure and biology

Often measurements or monitoring are not made at the appropriate spatial or temporal scales. Water quality monitoring samples taken in the middle of large embayments will miss phenomenon at the surface microlayer, water-sediment interface, or in shallow areas or areas of limited water circulation (lagoons), or in intertidal areas of periodic immersion/emersion. Sampling regimes should be designed to measure where the organisms are exposed to the stressor.

The time when organisms are exposed to stressors is also often missed in traditional sampling. Temporal sampling should reflect when an organism is present; this includes all phases of its life history. The scale of the duration of phenomenon also must be considered—plankton blooms occur over a few days, tidal cycles occur over hours. Also, most limiting factors are extremes—high lethal temperatures, for example.

Fortunately, inexpensive real-time data loggers are becoming more widely used and computers make data storage and analysis tractable. Biologists should become more familiar with them and use them more often.

Basic Biology
Salmon restoration efforts in the nearshore environment have pointed out the relative lack of knowledge about some of the basic biology of this organism at certain times in its life history. Determining the risks to herring and other forage fish have been hampered by lack of basic biological knowledge of larval and juvenile feeding, migration, and predation. Gut analysis and tagging is not as widespread as it was 25 years ago.

Ecosystem model
Food web modeling is a critical step, allowing scientists and managers to make the conceptual connection between different parts of the ecosystem, and then determining appropriate management actions based on cause/effect. Several Puget Sound ecosystem models have been created and are in various stages of verification (Newton and others 2000; NearPRISM, http://www.prism.washington.edu/, http://www.prism.washington.edu/science/projects/nearshr.html, http://courses.washington.edu/ocea506b/week1.html; SPASM, http://www.ecy.wa.gov/programs/eap/spasm/spasm_descrip.htmlPSAMP). Simple models can also be used to popularize restoration efforts (The Chesapeake Bay Program, 2001).

Little is known about the base of the food web. While overall primary productivity has been measured, few researchers routinely count and identify plankton. A well known, if poorly understood, consequence of eutrophication is in phytoplankton and zooplankton community structure. The increase of toxic algal blooms in Puget Sound might be taken as an indication of similar shifts here. Little is understood about the consequences of shifts in lower trophic levels on the availability of prey for larval stages, which in turn affect the upper levels.

Water Quality in the "corners"
Studies done at NMFS's Auk Bay laboratory recently found that very low levels (1 ppb) of aqueous poly-aromatic hydrocarbons (PAHs) impact herring and salmon larvae (Carls and others 1999). These data begin to raise the possibility that some organisms may be under chronic sub-lethal impacts at ambient or background levels of PAHs, especially in areas of concentration such as the water-air and water-sediment interfaces.

Problems may be even more severe in "corners." We may not be looking in the right places. Most monitoring is done in the middle of the bay. Because the nearshore environment is very complex—the intertidal is in and out of water and the shallow subtidal is often said to be "too shallow for oceanographers and too deep for hip boots." Newton has found that embayments are where stratified water columns and poor circulation lead to hypoxic conditions. (Newton and Reynolds Draft.).

Gardiner (Gardiner 1992) and Hardy (Hardy and others1987a; Hardy and others1987b; Hardy 1997) have studied the air-water interface and surface microlayer. They have observed what they called the "bath tub ring effect"—concentrated surface microlayer coats the intertidal in flooding and ebbing tides, exposing benthic organisms and eggs to up to 1000x concentration of some pollutants.

The water-sediment interface is where benthic organisms live and experience environmental conditions. The microhabitat is seldom studied.

Impacts from cryptic non-indigenous species
Recent exotics expeditions (Cohen and others1998) found ten new non-indigenous species, raising the known total to 52. Importantly, most of the species found were cryptic, yet many could have profound impacts on food web dynamics. A better understanding of the ecological impacts of these species is critical.

Links between all the above
It is too simplistic to say "loss of habitat." Often this is taken to mean the physical loss of habitat—fill, dredge, diking, etc. What is now becoming more apparent, but much more difficult to understand and monitor, is the loss of function. The beaches may appear to still be there—a quick glance would be

satisfactory to say they're fine. We should be looking for chronic sub lethal impacts on functions - eutrophication and strange chemicals don't destroy habitat, they destroy functions.

What can we do?

Change the Paradigm
Site-by site-habitat loss is slowing. Most filling and diking and other largely irreversible absolute conversions have stopped Unfortunately, most regulatory programs are still aimed at single-site and point source control. Nonpoint sources and "background levels" of pollutants are increasingly important, which will be harder to monitor, regulate, and measure. However, this is changing—planning is now being approached on a watershed basis.

Prevent further loss
The lesson to be learned is that an "ounce of prevention is worth a pound of cure." Reversing downward trends and restoring ecosystems is expensive, uncertain, and frankly, unnecessary. Recovery in the Chesapeake Bay, while initially optimistic and seemed to be succeeding, has faltered. Water clarity, a positive indicator of eutrophication, increased after initial cleanup efforts, but is now slowing decreasing. (Fig. 3) or trending downward (Fig. 4).

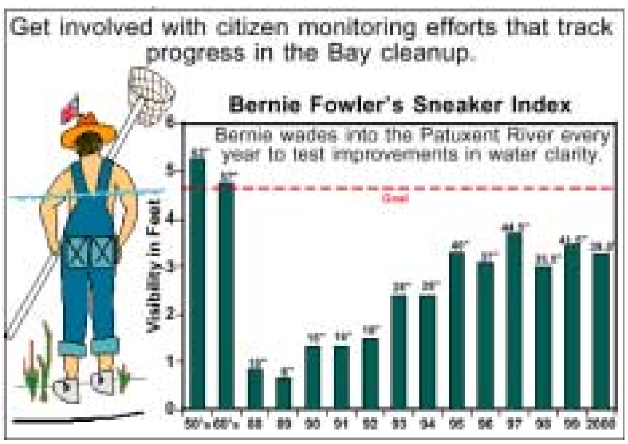

Figure 2 Water Clarity as measured by the Sneaker Index (From: The Chesapeake Bay Program 2001)

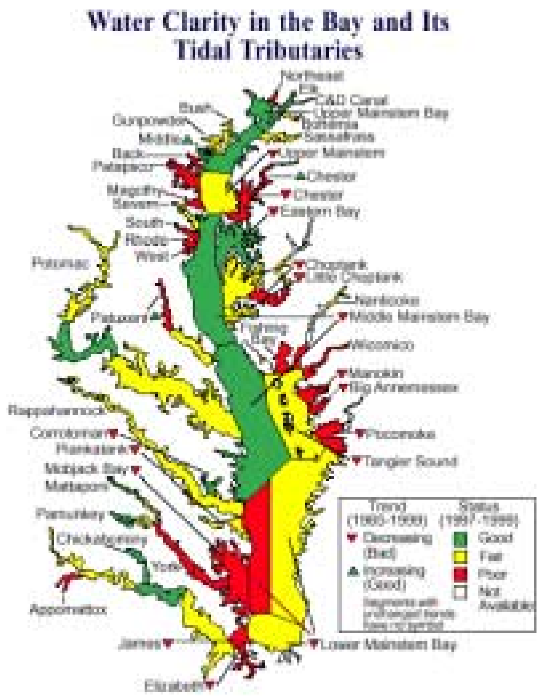

Figure 3 Trends in water clarity in Chesapeake Bay (From: The Chesapeake Bay Program 2001)

Model the ecosystem

A model provides a conceptual framework upon which hypotheses can be tested. A model must consider all inputs into the aquatic environment, including groundwater and aerial deposition. It also must have appropriate temporal and spatial scales that account for all stages of life–histories and their locations at specific times. Several Puget Sound ecosystem models have been created and are in various stages of verification (Newton and others 2000; NearPRISM, http://www.prism.washington.edu/, http://www.prism.washington.edu/science/projects/nearshr.html, http://courses.washington.edu/ocea506b/week1.html; SPASM, http://www.ecy.wa.gov/programs/eap/spasm/spasm_descrip.htmlPSAMP)

Test linkages- demonstrate cause/effects

Models are only hypotheses–they must undergo verification, either through formal research projects or from "experimental management" (see URL's above)

Learn from our own experiences

Creating a formal feedback system is important to avoid making the same mistakes (Santillo; Stringer; Johnson, and Tickner 1998). However, careful monitoring and response is not enough. Walters (Walters 1997) argues that the first step is to make a dynamic model that will identify gaps in knowledge, and that often the best way to fill these gaps is through "experimental management."

Perform basic research on biology of Puget Sound organisms

Fundamental life-history biology and ecology of many key organisms is needed. Trophic relationships are poorly understood or quantified. Shifts in food web structure may not be detected using current understanding.

Collect and analyze tribal, anecdotal, historical, unpublished, and "gray" information

There is wealth of old information that has been largely ignored or thought to be of little value, such as WDFW surveys, fishermen, tribal members, long-time beachfront property owners. This source of information on historical abundance distribution, and relationships needs to be systematically collected and analyzed.

Summary
Puget Sound is not unique. It is bound by the same ecological principles, has the same response to stressors, and is populated by people who appear to react to bad news in the same manner as those living elsewhere. It is hoped that this discussion will point out that we are doomed to repeat history unless we learn from it.

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